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An analysis of the mode of operation of inertia type fuzes in
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ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

A.R.D.E. MEMORANDUM (S)45/57

An analysis of the mode of operation of inertia type fuzes in
Squash Head Shells

J. S. Buchanan (S10)

H. J. James (S10)

Summary

A study is made of the mechanism of operation of inertia fuzes in H.E.S.H. shells. The propagation of the compressive shock waves through the shell is analysed and an estimate made of the time required for the fuze to function. The result is compared with experiment and its relevance to the design of the H.E.S.H. shell discussed.

Approved for issue:

W. M. Evans, Principal Superintendent 'S' Division

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1. INTRODUCTION

1.1 Recent experimental studies [1] of the mode of collapse of squash head shells on impact with the target have demonstrated that the performance of the shell is affected by the functioning time of the fuze. Furthermore, the time of functioning of the fuze will need to be different for different angles of attack and shell velocities. Therefore before a specification can be placed on the design of a fuze it is necessary to determine the time delays necessary for the optimum performance of the shell for all these conditions of attack. Unfortunately information is very limited [2, 3, 4] and it is recommended that the dynamic pattern of the collapse for all types of squash head shell (without fuzes) should be determined experimentally for different angles of attack and shell velocities. Static firings should then be carried out to determine the disposition of explosive on the plate which gives the optimum scabbing performance. This can then be related to the dynamic patterns and fuze functioning times specified accordingly. Unless this is done we cannot give precise requirements for the design of the fuze. We can however investigate the mechanism of activation of existing fuzes and this report outlines a study of the inertia fuze and its activation by the compressive waves generated at the nose of the shell during impact.

2. MECHANISM OF FUZE FUNCTIONING

2.1 Figure 1 shows the design of a typical base fuze (L 15A2) which is incorporated in squash head shells. This fuze works on an inertia principle insofar as the needle is free to move forward relative to the fuze when the latter is decelerated. It will be shown that the creep spring A will provide little constraint on the relative movement of the needle and fuze during impact and only serves to prevent forward motion of the needle during the flight of the shell. Figure 2 is a complete drawing of a shell and fuze. It is clear that the fuze can only be decelerated by shock waves through the shell wall or by shock waves through the explosive filling or by direct impact of the fuze on the target plate (after the shell wall has dis-integrated). The last is not a desirable feature for this particular fuze, though a direct shock transmission link for the transfer of shock waves to the fuze has been suggested. Of the other two mechanisms the second has been considered the most feasible although there has been no direct evidence to support this or to negate the first. Unfortunately there is very little if any information to be found on the propagation of non-reacting shock waves through explosives [5]. There is however a large amount of data available on shock propagation in steels [6, 7, 8] and relations have been established between particle and shock velocities and the amplitude of the shock and this has been applied in this report.

In order to assess the total time of functioning of the fuze it is necessary to analyse the collapse of the shell. When the nose of the shell strikes the target, which we will assume is rigid, compression waves are transmitted from the nose through the filling and shell wall at velocities much greater than the shell velocity and these waves discontinuously drop the velocity of the oncoming material. Until these waves reach any particular point in the material, the material beyond that point will not be affected by the impact of the nose and will move forward at the pre-impact velocity. The velocities of these waves are high but nevertheless impose a finite time before the base of the shell suffers any deceleration. Thus we have the interval T_1 , the initial shock transmission time which is not the same for the shock waves through the wall as for shock waves through the filling. When these waves reach and are refracted into the fuze it is assumed that little is transferred across the interface between the fuze wall and the striker pin with the result that the striker pin moves forward relative to the fuze at a velocity roughly equal to the particle velocity associated with the shock waves in the fuze wall. Subsequent reflections of these shock waves at free surfaces (the base) and at the nose cause further sharp decreases in the

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velocity of the fuze and hence increases in the relative velocity of the striker pin. The initial relative velocity of the striker pin will be of the same order as the particle velocity in the wave which is approximately $1/30$ of the shell velocity. Therefore the second time factor T_2 is introduced, the time of traverse of the needle. The needle then has to penetrate the sheath of the detonator and travel a finite distance inside the detonator [9] before initiation takes place and this will take a time T_3 . The fourth time interval, T_4 , will be the propagation of the detonation from the detonator to the target surface. Thus the total time of functioning of the fuze is given by

$$T = T_1 + T_2 + T_3 + T_4$$

Time of Traverse
Travel of needle
Travel in detonator
Detonation propagation

and the only apparent control on this delay is in the time T_2 , by means of variation of the length of the traverse of the striker pin. No attempt is made to compensate T for angle of attack.

We can make fairly accurate predictions of the values of T_1 , T_3 and T_4 but the determination of the value of T_2 is complicated by a lack of knowledge of the shock propagation parameters in the explosive and metal. However we can estimate fairly satisfactorily and then compare with the limited information available on the actual deceleration of the fuze.

3. SHOCK PROPAGATION THROUGH THE FILLING

3.1 When the shell arrives at the target a shock wave is initiated at the zone of impact and travels back through the filling. In a one dimensional model the amplitude of the shock wave will be such as to bring each plane of the filling to rest as the shock crosses it. The shock wave generated in a shell on impact however will be attenuated as it propagates through the filling due to the lateral expansion and therefore the oncoming material is not brought to rest but to a velocity lower than the original velocity of the shell. Due to the lateral expansion the stagnation zone is limited and we can visualize a conical shaped stagnation zone being established.

In order to obtain a rough quantitative picture of the process we will consider a one dimensional picture of a semi infinite mass of filling moving with velocity u striking a rigid semi infinite target and a shock moving backwards with velocity D in space leaving the filling at rest behind it.



Consideration of the conservation of mass gives

$$(1) \quad \rho_1 (D + u) = \rho_2 D$$

where ρ_1 and ρ_2 are the densities of the filling in front of and behind the shock wave respectively.

Conservation of momentum demands that

$$P - p = \rho_1 u (D + u)$$

where p and P are the pressures in the filling in front of and behind the shock wave respectively. In practice $P \gg p$ thus we may write

$$(2) \quad P = \rho_1 u (D + u) = \rho_1 u \Delta \text{ where } \Delta = \text{shock velocity relative to filling}$$

The shock will propagate through the filling until it reaches the fuze where part of the energy in the shock will be transmitted and

reflected. The pressure transmitted into the fuze depends on the relative shock impedances of the filling and the fuze material and is given by

$$(3) \quad \frac{P_2}{P_1} = \frac{\rho_2 \Delta_2}{\rho_1 \Delta_1} \frac{(\rho_1 \Delta_1 + \rho_3 \Delta_3)}{(\rho_2 \Delta_2 + \rho_3 \Delta_3)}$$

where the subscripts 1, 2, 3 refer to the filling ahead of the shock wave, the material of the fuze and the filling behind the shock wave respectively.

If we make the usual approximation that

$$\rho_1 \Delta_1 = \rho_3 \Delta_3$$

equation (3) becomes

$$(4) \quad \frac{P_2}{P_1} = \frac{\rho_2 \Delta_2}{\rho_2 \Delta_2 + \rho_1 \Delta_1}$$

If we consider an aluminium fuze body ($\rho_2 = 2.7 \text{ gm/cc.}$, $\Delta_2 = 7,300 \text{ m/sec.}$) and a filling ($\rho = 1.6 \text{ gm/cc.}$)

$$(5) \quad \begin{aligned} P_2 &= 1.85 P_1 & \text{for } \Delta_1 &= 1000 \text{ m/sec.} \\ P_2 &= 1.7 P_1 & \text{for } \Delta_1 &= 2000 \text{ m/sec.} \\ P_2 &= 1.5 P_1 & \text{for } \Delta_1 &= 4000 \text{ m/sec.} \end{aligned}$$

Thus the amplitude of the shock transmitted to the fuze is 50% greater than the amplitude of the incident shock. The part of the shock which is reflected at the fuze will travel back to the target plate or stagnation zone where it will be reflected again. The reflected shock is being attenuated all the time and it seems very unlikely that it can contribute appreciably to the deceleration of the fuze except during the later stages of the impact when the fuze has nearly reached the target plate or stagnation zone. We can therefore visualize the subsequent deceleration in terms of a gradually increasing retarding force as the fuze moves into denser material.

We can calculate the pressure in the shock wave at the point of impact from equation (2). If we take $\rho = 1.6 \text{ gm/cc.}$, $u = 625 \text{ m/sec.}$

we get that $P = 1.10^{10} \text{ dynes/cm}^2$ for $\Delta = 1000 \text{ m/sec.}$
 $2.10^{10} \text{ dynes/cm}^2$ for $\Delta = 2000 \text{ m/sec.}$
 $4.10^{10} \text{ dynes/cm}^2$ for $\Delta = 4000 \text{ m/sec.}$

This is the initial pressure in the shock wave and we have no quantitative knowledge how rapidly the shock is attenuated. However, it is possible to obtain some idea of the maximum attenuation in the filling which allows the shock wave through the filling to play an appreciable part in the deceleration of the fuze. To produce a measurable^{*} deceleration it is necessary for the shock wave in the aluminium fuze to have a particle velocity of at least 10 m/sec. (see later).

Using equation 2

$$P_{Al} = 2.10^9 \text{ dynes/cm}^2$$

therefore from 5

$$P_F = 1.3 \times 10^9 \text{ dynes/cm}^2 \text{ for } \Delta = 4000 \text{ m/sec.}$$

* Capable of resolution by high speed photography.

P_F is the pressure in the filling at the boundary of the fuze while the initial pressure in the shock wave at the target interface is less than $4 \cdot 10^{10}$ dynes/cm². Therefore the maximum attenuation is a factor of 30 in the amplitude of the shock wave as it travels from the point of impact to the fuze - initially 10 in. in the 120 mm. H.E.S.H. shell.

If the attenuation is greater than this, the shock through the filling is not an important contributor to the initial deceleration of the fuze.

4. SHOCK PROPAGATION THROUGH THE SHELL WALL

4.1 The impact of the shell on the target will cause a shock to be set up in the wall of the shell as well as in the filling. The amplitude of the shock is given by equation (2). Putting $\rho = 7.7$ gm/cc. we get

$$P = 2.7 \times 10^{11} \text{ dynes/cm}^2$$

304,100 psi
This is considerably above the dynamic yield strength of mild steel $2 \cdot 10^{10}$ dynes/cm² and extensive plastic flow occurs. In steel an elastic displacement is propagated at a greater velocity than plastic waves of the amplitudes reached under these conditions. Therefore an elastic wave will travel down the wall of the shell followed by the plastic disturbance. The plastic wave will be severely attenuated and while no detailed figures are available the work of Taylor [10] and the radiographs of Buchanan and Costello [1] show that the measurable plastic disturbance will not spread further than 2 in. from the impact zone. Thus the effect of the plastic wave through the wall of the shell can be ignored until the late stages of the collapse of the shell.

It is not possible to ignore the elastic wave through the shell walls as we did the elastic wave in the filling. Any elastic wave in the filling would have a very small amplitude since the yield strength is low. The amplitude of the elastic wave propagated along the shell wall is initially equal to the dynamic yield strength of the material, i.e. $2 \cdot 10^{10}$ dynes/cm² with a corresponding particle velocity of 50 m/sec. The elastic wave will attenuate as it passes along the shell wall though the attenuation of elastic waves in steel is very low.

When the wave reaches the aluminium fuze, the particle velocity will be enhanced. However there will be a considerable loss of amplitude due to the expansion of the elastic wave from the thin wall of the shell to the larger area of the fuze. Thus we expect that the particle velocity in the fuze due to the elastic wave along the shell wall will be considerably smaller than 50 m/sec. The elastic wave will pass through the fuze and be reflected at the fuze-air surface at the back of the shell with a resultant deceleration of the rear of the shell by twice the particle velocity in the wave. The reflected wave will pass back along the shell walls to the impact zone or plastic wave front where it will be reflected again. There is sufficient time in the early stages of the impact (i.e. before the fuze gets within about 1 in. of the target) for an elastic wave to be reflected several times from the base of the shell and each reflection will introduce a deceleration of twice the particle velocity. *S*

5. COMPARISON WITH EXPERIMENTAL RESULTS

5.1 Fastax camera records (figure 3) of the collapse of the squash head shell on the target enable a direct measurement of the deceleration of the fuze to be made. In sections 3 and 4 it was shown that an elastic wave down the shell wall would decelerate the fuze and that possibly the plastic wave through the filling would assist.

It is possible to compute the deceleration produced by the elastic waves down the shell wall if a particle velocity is assumed. This will then be compared with the experimental results and the result will indicate what part, if any, the plastic wave through the filling plays.

The procedure is shown in figure 4. This is a distance time plot of the shell and AB represents the movement of the base of the shell before impact, which occurs at time E. The nose stops and the elastic wave passes back along the shell wall and reaches the base at time D. The wave is reflected and the velocity of the base is reduced by twice the particle velocity. The reflected wave travels back to the target where it is reflected once more. The wave is traced through several reflections and each reflection at the base of the shell produces a deceleration of the fuze whose path is given by D.E.F.G. In figure 4 the particle velocity in the elastic wave in the fuze is taken as 20 m/sec. A similar procedure is followed in figure 5 except a particle velocity of 10 m/sec. is used. In figures 6 and 7 the same thing has been done for the 30mm. model H.E.S.H. shell and particle velocities of 10 and 6 m/sec. are used. On all the figures positions of the base of the shell with respect to the target are plotted as measured from Fastax camera (120mm. shell) and spark shadowgraph (30mm. shell) records.

In figure 4 where a particle velocity of 20 m/sec. is used, it is seen that in the early stages of the impact the calculated deceleration of the base is too rapid. In figure 5 a particle velocity of 10 m/sec. is used and a much better fit is obtained. Similarly in figure 6 a particle velocity of 10 m/sec. gives good agreement with the experimental points while a particle velocity of 6 m/sec. (fig. 7) gives a calculated deceleration which is too slow. It appears that the elastic wave down the shell wall giving a particle velocity of about 10 m/sec. in the fuze is sufficient to explain the measured deceleration of the shell during the early stages of the impact. It is seen that, as expected, the deceleration increases rapidly in the later stages of the impact and this increase in the rate of deceleration occurs when the leading edge of the fuze has reached a distance less than about $1\frac{1}{2}$ in. from the target. At this stage the fuze is entering the stagnation zone and the resistance to flow by the compressed explosive undoubtedly contributes to the retardation. During the early stages (up to 300μ sec) of collapse however, it seems more likely that the shock propagation through the walls determines the pattern of retardation of the base of the shell.

6. ESTIMATION OF T

6.1 The initial shock Transmission Time - T_1 .

This is the time taken for the shock waves generated at the impact to reach the fuze.

Time for waves through shell wall is

$$\frac{L}{V} \text{ sec.}$$

Velocity of elastic waves along shell wall is $\sqrt{E/\rho} = 5200 \text{ m/sec}$ and the distance L is 40.6 cm.

$$T_1 = 78 \mu \text{sec.}$$

Time for shock wave through filling to reach fuze is

$$\frac{d}{\Delta}$$

d is 27 cm.

$$\begin{array}{ll} \text{Therefore } T_1 = 68 \mu \text{ sec.} & \text{for } \Delta = 4000 \text{ m/sec.} \\ T_1 = 135 \mu \text{ sec.} & \Delta = 2000 \text{ m/sec.} \\ T_1 = 270 \mu \text{ sec.} & \Delta = 1000 \text{ m/sec.} \end{array}$$

It is unlikely that the velocity of the shock through the filling is as high as 4000 m/sec. thus the value of 78 μ sec. obtained for the shock through the shell wall is the best estimate of T_1 .

6.2

Time of Traverse of Needle - T_2

We saw in 5 that a wave with a particle velocity of 10 m/sec. would explain the measured deceleration of the shell base. Thus once the shock wave passes the fuze the striker pin will have a velocity of 10 m/sec. relative to the rest of the fuze. The striker pin will continue with this relative velocity until time t_2 when the wave passes through the fuze again after reflection at the base of the shell. The relative velocity of the striker pin is then increased to 20 m/sec. and remains at this value until t_3 when it is again increased to 30 m/sec. by the elastic wave returning from the nose of the shell.

Thus we have

Time after impact μ sec.	Relative Velocity of Striker Pin and Fuze m/sec.	Distance moved mm.
0 - 78	0	0
78 - 102	10	0.24
102 - 218	20	2.32
218 - 242	30	0.72
242 - 324	40	3.29

The total distance the striker pin has to move is about 5 mm which on the above basis would take 207 μ sec. ($T_2 = 285 - 78 = 207 \mu\text{sec.}$)

The above calculation of the time makes two assumptions

- (1) When the shock passes through the fuze nothing is transmitted to the striker pin which continues with undiminished velocity.
- (2) The effect of the creep spring is negligible. This is reasonable since the spring is made to withstand accelerations of 20g while the deceleration involved in the collapse of the shell on the target is about 1000 times greater. (From fig.5)

6.3

Time for Detonator to Function - T_3

The time for the detonator to function is taken from a report by Porter [9]. He stated that the needle has to penetrate a distance between 0.013 in. and 0.030 in. before a sensitive spot which will give rise to a fire is found. The velocity of the needle is therefore important. If we take the velocity of propagation of the reaction through the initiating compound as 150 ft/sec. the report shows that the time of functioning of the detonator should be between 52 and 56 μ sec. after the needle enters the initiating compound, with a velocity of 40 m/sec. Thus we can take $T_3 = 54 \mu$ sec. for a 1.7 grain "A" composition detonator.

It is of interest that if we try to decrease T_2 by reducing the distance the needle has to move we reduce the velocity of the needle when it enters the detonator and therefore increase T_3 . If the velocity of the needle is 20 m/sec. then the time of functioning of the detonator is between 60 and 80 μ sec. i.e.

T_3 is increased by about $20 \mu\text{sec}$. while T_2 can be reduced by up to $140 \mu\text{sec}$. giving a net reduction in T of $120 \mu\text{sec}$. However if we try to reduce T_2 still further by reducing the distance the needle has to move we reduce the velocity of the needle to 10 m/sec . and the time T_3 increases rapidly and the overall result is an increase in T .

6.4 Propagation of Detonation Wave - T_4

By the time the detonator has functioned ($T_1 + T_2 + T_3$) there will only be a thickness of 7.8 cm . of high explosive including the C.E. Pellet between the fuze and the plate. Taking the velocity of detonation as $7,800 \text{ m/sec}$. we get T_4 to be $10 \mu\text{sec}$.

6.5 Combining $T_1 + T_2 + T_3 + T_4$ we get that $T = 349 \mu\text{sec}$. This is the time from the impact of the shell on the target until the detonation wave reaches the surface of the target.

7. DISCUSSION

7.1 One of the most interesting features of the impact of H.E.S.H. shell on the target is the very low rate of deceleration of the base of the shell. This means that for any inertia type fuze located in the base of the shell the relative velocities of the parts of the fuze will be low. In the particular shell studied in this report the empirical results indicate that the velocity of the striker pin relative to the rest of the fuze is of the order of 30 m/sec . during the early stages of the impact. This velocity is so low that it takes the striker pin an appreciable time to move into the initiating compound. Thus it should be possible to vary the time for the fuze to function by varying the distance the needle has to move and we understand experiments along these lines are proceeding. However if the needle is placed too close to the initiating compound it will acquire a very low velocity before entering the initiating compound and the time for the compound to ignite will increase. There is a possible minimum time for the functioning of the fuze ($T_2 + T_3$) and it is $95 \mu\text{sec}$. and this occurs when the needle moves 0.25 mm . before entering the compound. However for the type of fuze we are considering, the design is such that the needle has to move about 5 mm . and therefore $T_2 + T_3 = 260 \mu\text{sec}$.

From our analysis the initiating compound should fire at $T_1 + T_2 + T_3 = 339 \mu\text{sec}$. after impact and by this time the leading part of the fuze is only 3.8 cm . from the surface of the target. Whether this is the position to give the optimum scabbing performance is not known and would have to be determined experimentally.

The early deceleration of the base of the shell could be due to either the shock through the filling or the shock through the walls though the case for the latter is more positive in the light of more factual evidence. We saw in section 3 that if the shock through the filling is to be important then the maximum permitted attenuation is a factor of 30. An attenuation of 30 over a distance, initially 10 in. is not unreasonably large and in fact more would be expected.

Experiments are being carried out by Hills at Cambridge to try and measure the velocity and attenuation of shock waves in explosives and initial results indicate a shock velocity less than 1000 m/sec . for impact velocities of 2500 ft/sec .

Experiments have been carried out [11, 12] in which the time interval between the impact of the shell and detonation occurring has been measured. Values between $400 \mu\text{sec}$. and $270 \mu\text{sec}$. have been measured for shells with velocities of impact between 1300 ft/sec . and 2600 ft/sec . The shorter

time interval corresponds to the shell with the higher velocity. From these results one would expect a delay of $\sim 320 \mu\text{sec}$. for a shell striking at 45° with a velocity of 2250 ft/sec. This agrees well with the estimate of $349 \mu\text{sec}$. obtained in section 6. The results of Hawkins and Taylor also show that by the time the shell detonates the fuze will be within $2\frac{1}{2}$ to 5 in. of the surface of the plate. This means that the column of explosive between the fuze and the target is very short or even non-existent since there is an inert pad 2.5 in thick in the nose of these shells. In no case did the shell detonate after the fuze had reached the target plate.

There is an additional effect which may be detectable. It is clear from equation 1 that the filling behind the shock wave has been compressed. This increase in density will increase the detonation velocity and also the detonation pressure. Using the values $u = 625 \text{ m/sec}$, $\rho_1 = 1.6 \text{ gm/cc}$. we find that the density is increased by

19%	when	Δ	=	4000 m/sec.
45%		Δ	=	2000 m/sec.
167%		Δ	=	1000 m/sec.

The dependance of the detonation velocity on density is given by [13.]

$$(6) \quad V = C + K(\rho - 1)$$

where C and K are constants. K is 3000 for RDX/TNT 60/40, therefore the detonation velocity is increased by

900 m/sec. for a 19% increase in density
2100 m/sec. " 45% " " "
8000 m/sec. " 167% " " "

The pressure in the detonation wave is obtained from equation (2) and if $u \approx \frac{1}{4}\Delta = \frac{1}{4}V$

$$(7) \quad P \propto \rho V^2$$

Using this relation the resultant increase in detonation pressure is

48% for a 19% increase in density

It is this increased pressure which is refracted into the target and its effect might be noticeable as an increase in scab momentum in dynamic firings over that obtained in static firings. However this increase in density will not be uniform due to lateral expansion and will be a maximum on the axis.

8. CONCLUSIONS

- (1) The mechanism of the action of inertia type fuzes located in the base of H.E.S.H. shell has been analysed. It has been shown that the relative velocity of fuze and striker pin is low and is about 30 m/sec.
- (2) The minimum time from impact for an inertia fuze in the base of a shell to function is estimated to be $\sim 175 \mu\text{sec}$. while for the normal X19E1 fuze the time is estimated to be $\sim 340 \mu\text{sec}$. This agrees well with direct measurements which give $320 \mu\text{sec}$.
- (3) There is no information available as to the time interval required between impact and fuze igniting to give optimum performance of the H.E.S.H shell. It is recommended that this information be obtained.

(4) Since the action of this type of fuze is inherently slow it is recommended that consideration be given to other types of fuzes and/or to methods of decreasing the response time of the fuze such as direct shock transmission links.

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SECRET/DISCREET

FIG 1

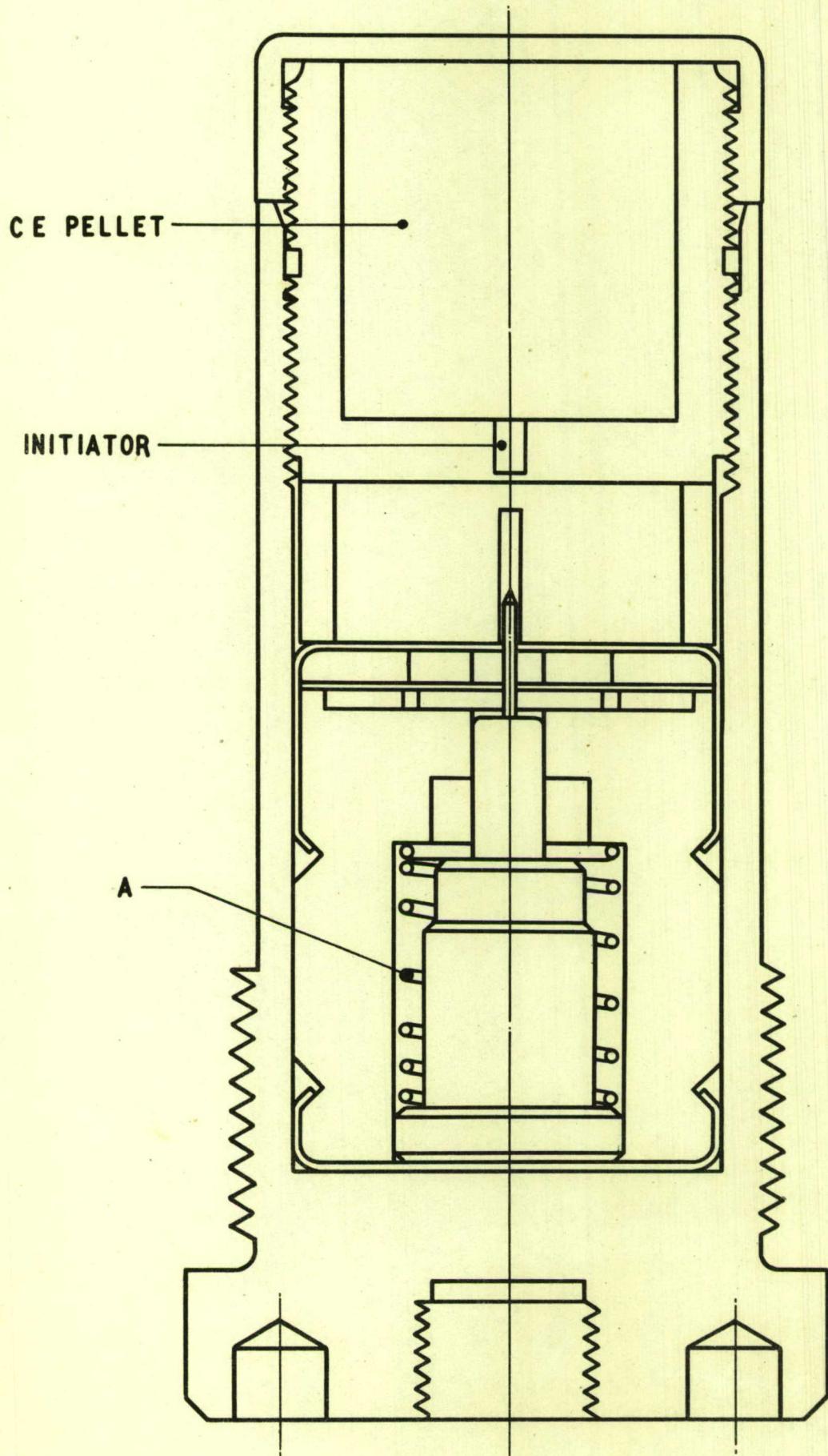


FIG 1 TYPICAL BASE FUZE

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FIG. 2.

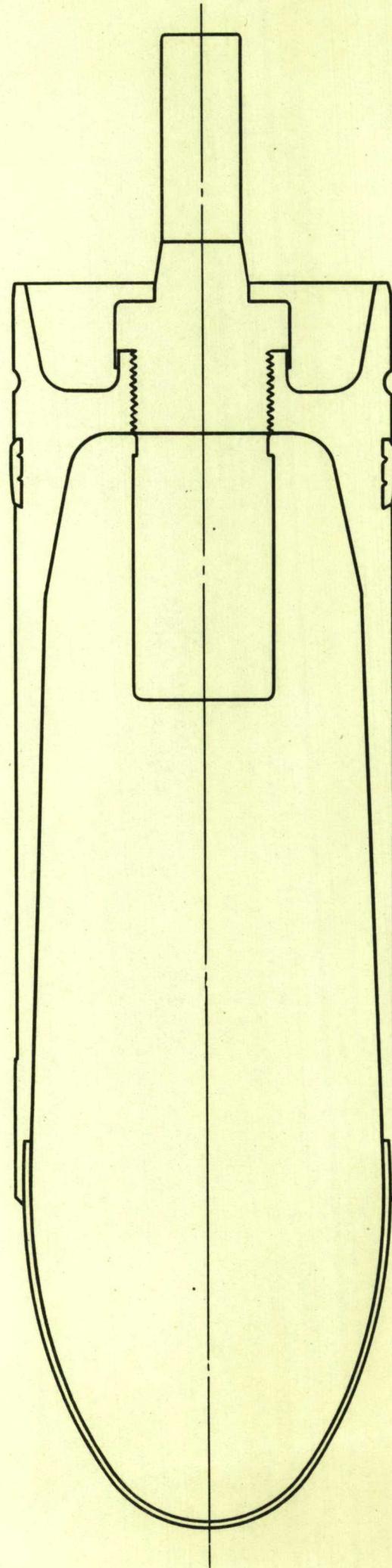


FIG. 2. TYPICAL H.E.S.H. SHELL WITH FUZE.

SECRET/DISCREET

SECRET/DISCREET

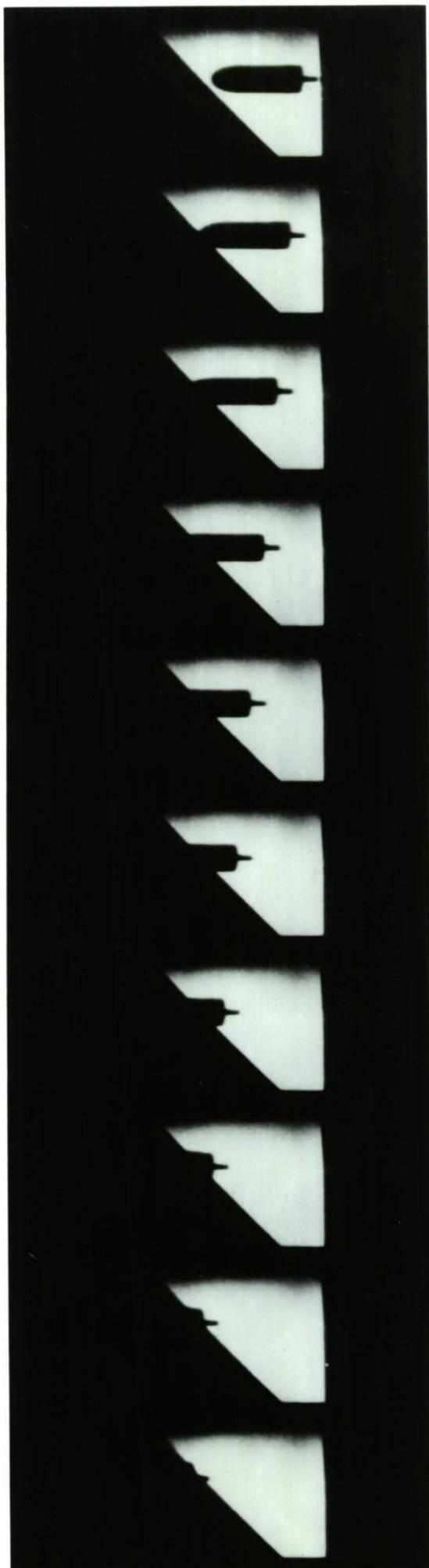
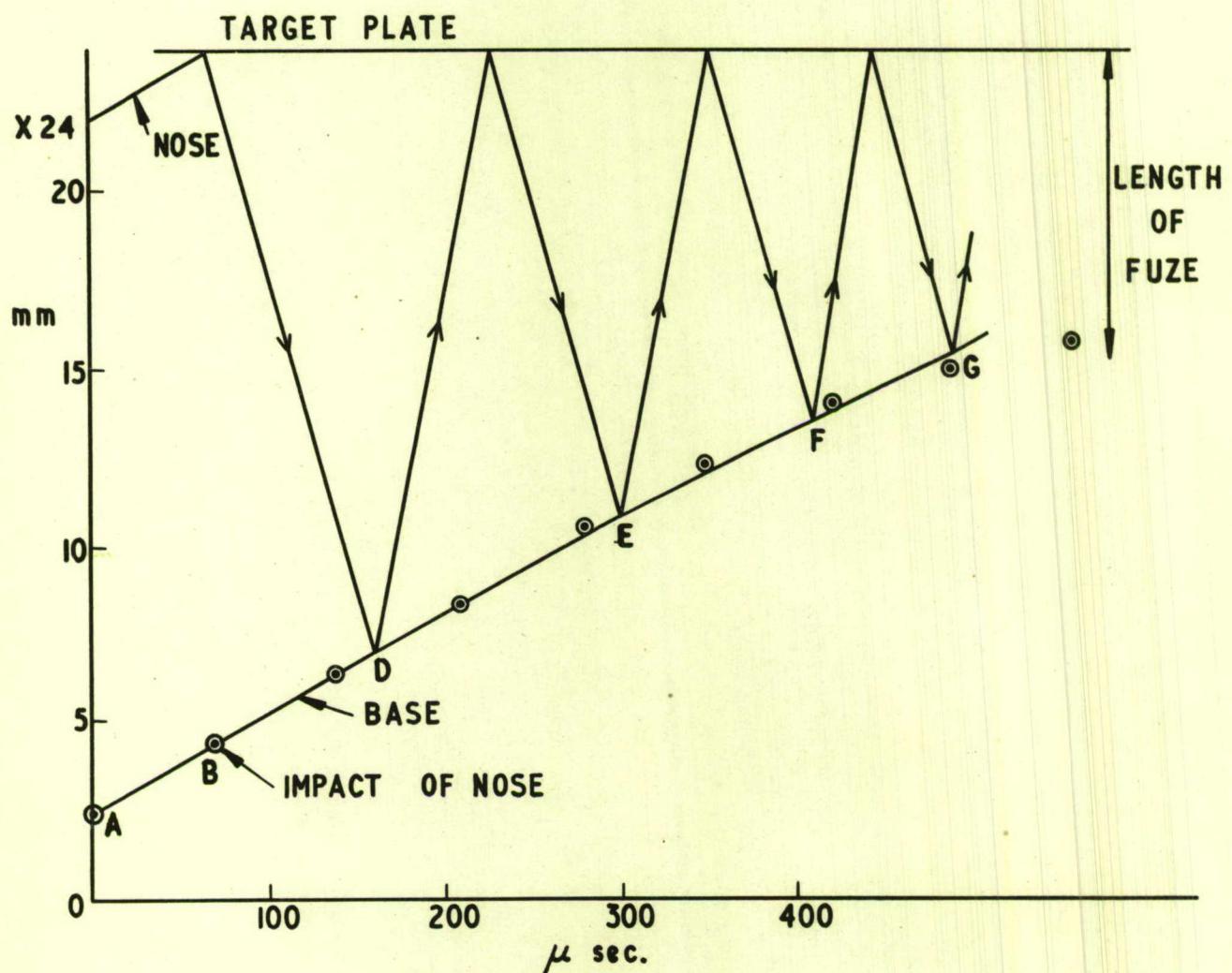


Fig. 3. Fastax camera photographs.
120 mm. H.E.S.H. Shell.
Angle 45°.

SECRET/DISCREET

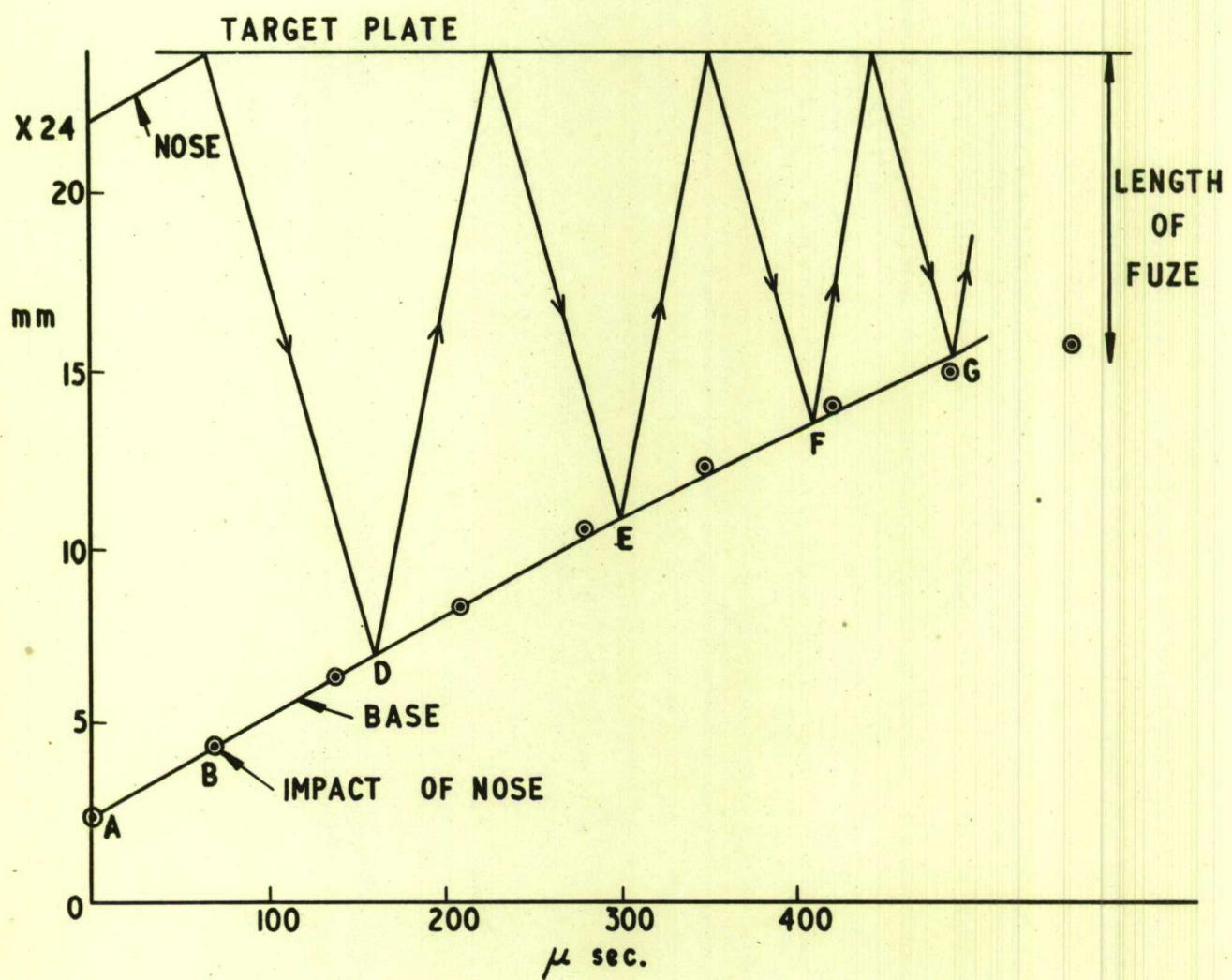


$$\text{VELOCITY OF ELASTIC WAVES} = \sqrt{\frac{E}{\rho}} = 5200 \text{ m/sec.}$$

$$\text{PARTICLE VELOCITY} = 20 \text{ m/sec.}$$

◎ = EXPERIMENTAL POINTS.

FIG.4. DISTANCE TIME PLOT 120 mm. H.E.S.H. SHELL.

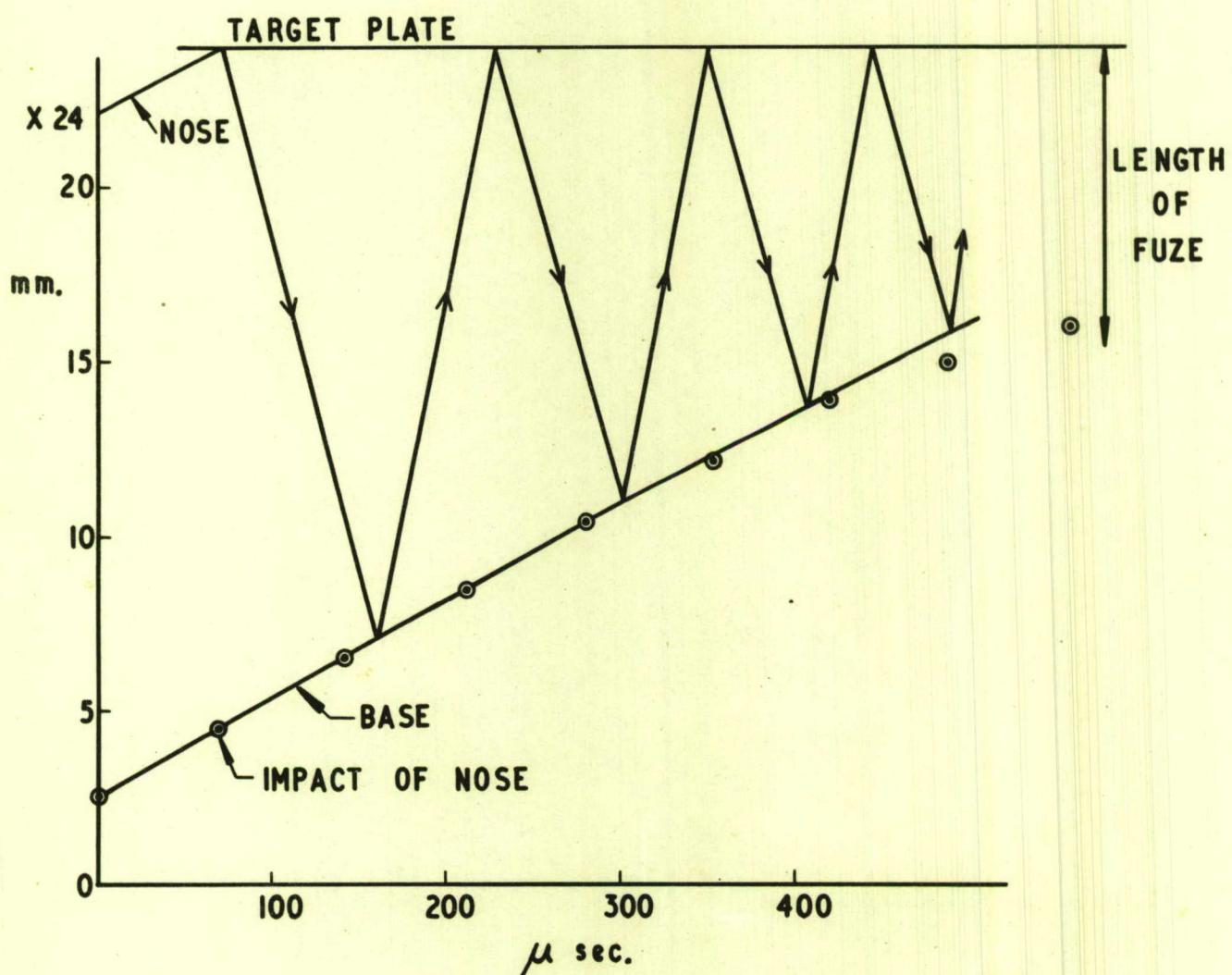


VELOCITY OF ELASTIC WAVES = $\sqrt{E/\rho}$ = 5200 m/sec.

PARTICLE VELOCITY = 20 m/sec.

◎ = EXPERIMENTAL POINTS.

FIG.4. DISTANCE TIME PLOT 120 mm. H.E.S.H. SHELL.

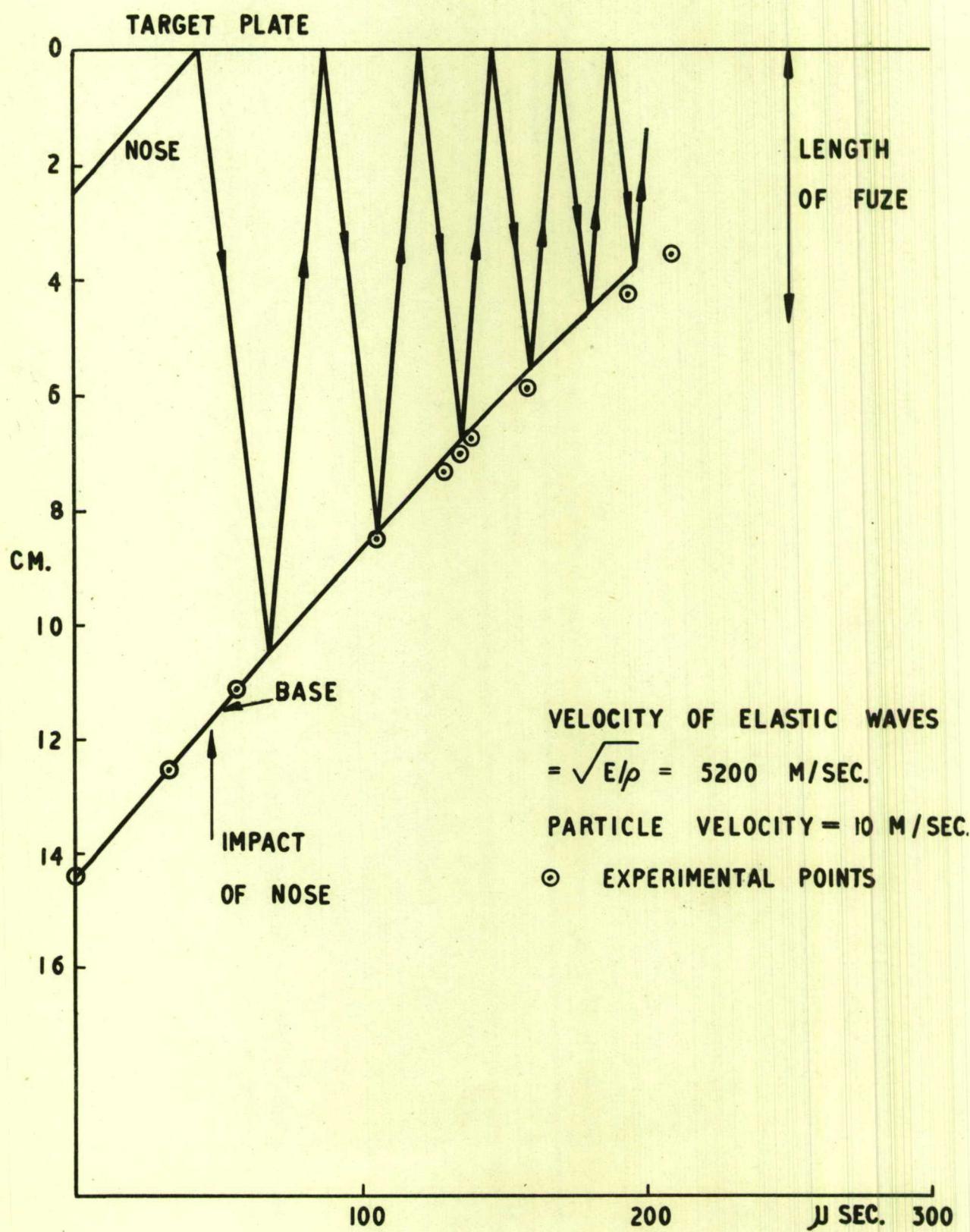


VELOCITY OF ELASTIC WAVES = $\sqrt{\frac{E}{\rho}} = 5200 \text{ m/sec.}$

PARTICLE VELOCITY = 10 m/sec.

◎ = EXPERIMENTAL POINTS

FIG.5. DISTANCE TIME PLOT 120 mm. H.E.S.H. SHELL.

FIG.6. DISTANCE - TIME PLOT 30 MM. MODEL H.E.S.H. SHELL.

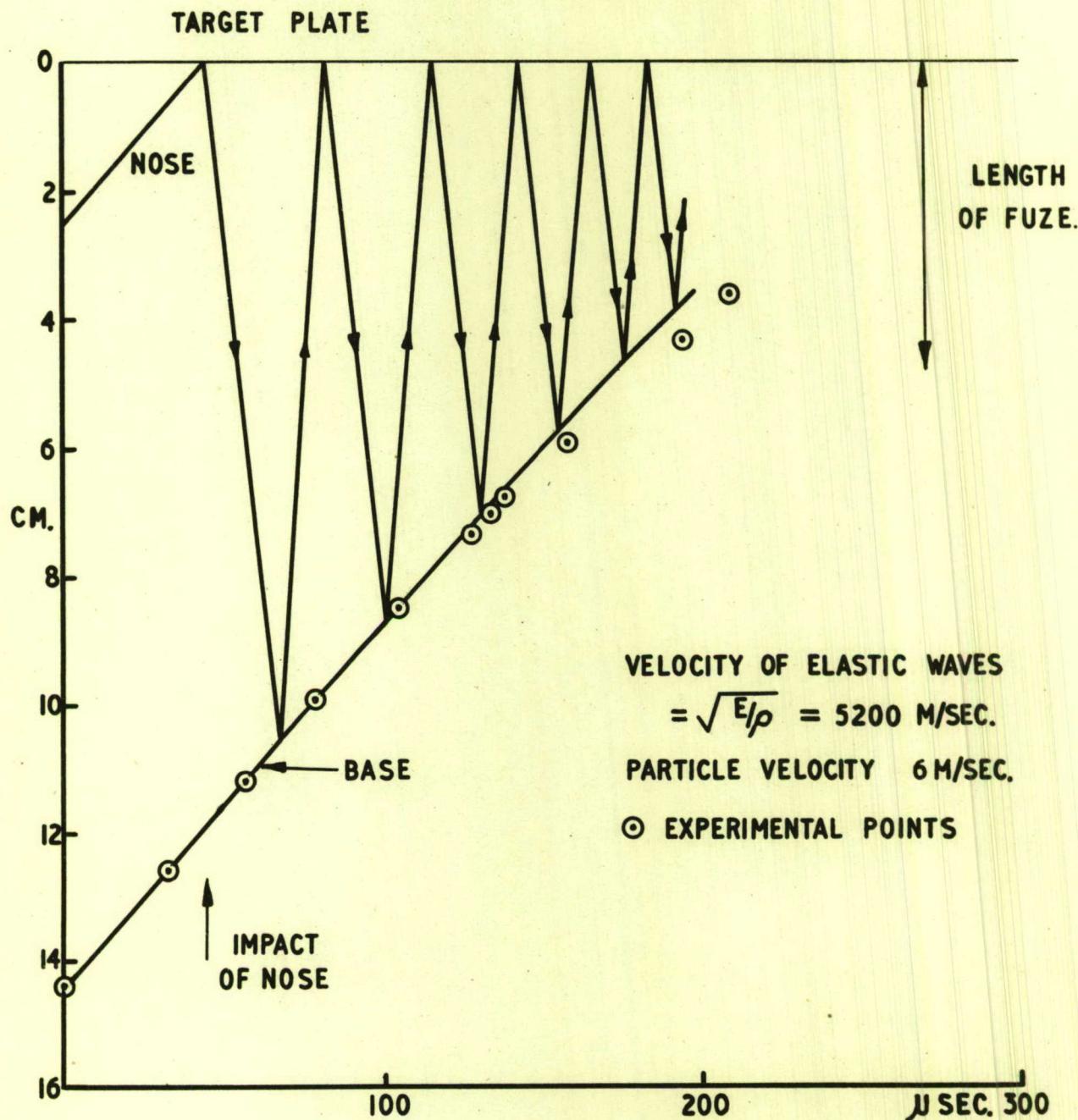


FIG.7. DISTANCE - TIME PLOT. 30 MM. MODEL H.E.S.H. SHELL.



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